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NASA Dryden Flight Research Center

"Rapid Deceleration Mode Evaluation"

Table of Contents

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#) [\[Submit Response / Read Responses\]](#)

[HELP](#) is Available

CONTENTS:

- [Abstract \(p. 1\)](#)
 - [Prediction of a Rapid Deceleration Mode Deceleration \(p. 2\)](#)
 - [Prediction of Engine Controls for a Rapid Deceleration Mode Deceleration \(p. 3\)](#)
 - [Prediction of Inlet Controls for a Rapid Deceleration Mode Deceleration \(p. 4\)](#)
 - [Flight Test Analysis for a Rapid Deceleration Mode Deceleration \(p. 5\)](#)
 - [Flight Test Analysis for a Rapid Deceleration Mode Deceleration \(p. 6\)](#)
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NASA Dryden Flight Research Center

"Rapid Deceleration Mode Evaluation", page 1

Abstract

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#)

Paper [\[Index / Next \]](#) [\[Submit Response / Read Responses\]](#)

HELP is Available

Aircraft with flight capability above Mach 1.4 normally have an RPM lockup or similar feature to prevent inlet buzz that would occur at low engine airflows. This RPM lockup has the effect of holding the engine thrust level at the intermediate power (maximum non-afterburning). For aircraft such as military fighters or supersonic transports, the need exists to be able to rapidly slow from supersonic to subsonic speeds. For example, a supersonic transport that experiences a cabin decompression needs to be able to slow/descend rapidly; and this requirement may size the cabin environmental control system. For a fighter, there may a desire to slow/descend rapidly, and while doing so to minimize fuel usage and engine exhaust temperature. Both of these needs can be aided by achieving the **minimum** possible overall net propulsive force. As the intermediate power thrust levels of engines increase, it becomes even more difficult to rapidly slow from supersonic speeds.

Therefore, a mode of the PSC system to minimize overall propulsion system thrust has been developed and tested. The Rapid Deceleration mode reduces the engine airflow consistent with avoiding inlet buzz. The engine controls are trimmed to minimize the thrust produced by this reduced airflow, and moves the inlet geometry to degrade the inlet performance. As in the case of the other PSC modes discussed earlier, the best overall performance (in this case the least net propulsive force) requires an integrated optimization of inlet, engine and nozzle variables. This paper presents the predicted and measured results for the supersonic minimum thrust mode, including the overall effects on aircraft deceleration.

Paper [\[Index / Next \]](#) [\[Submit Response / Read Responses\]](#)

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"Rapid Deceleration Mode Evaluation", page 2

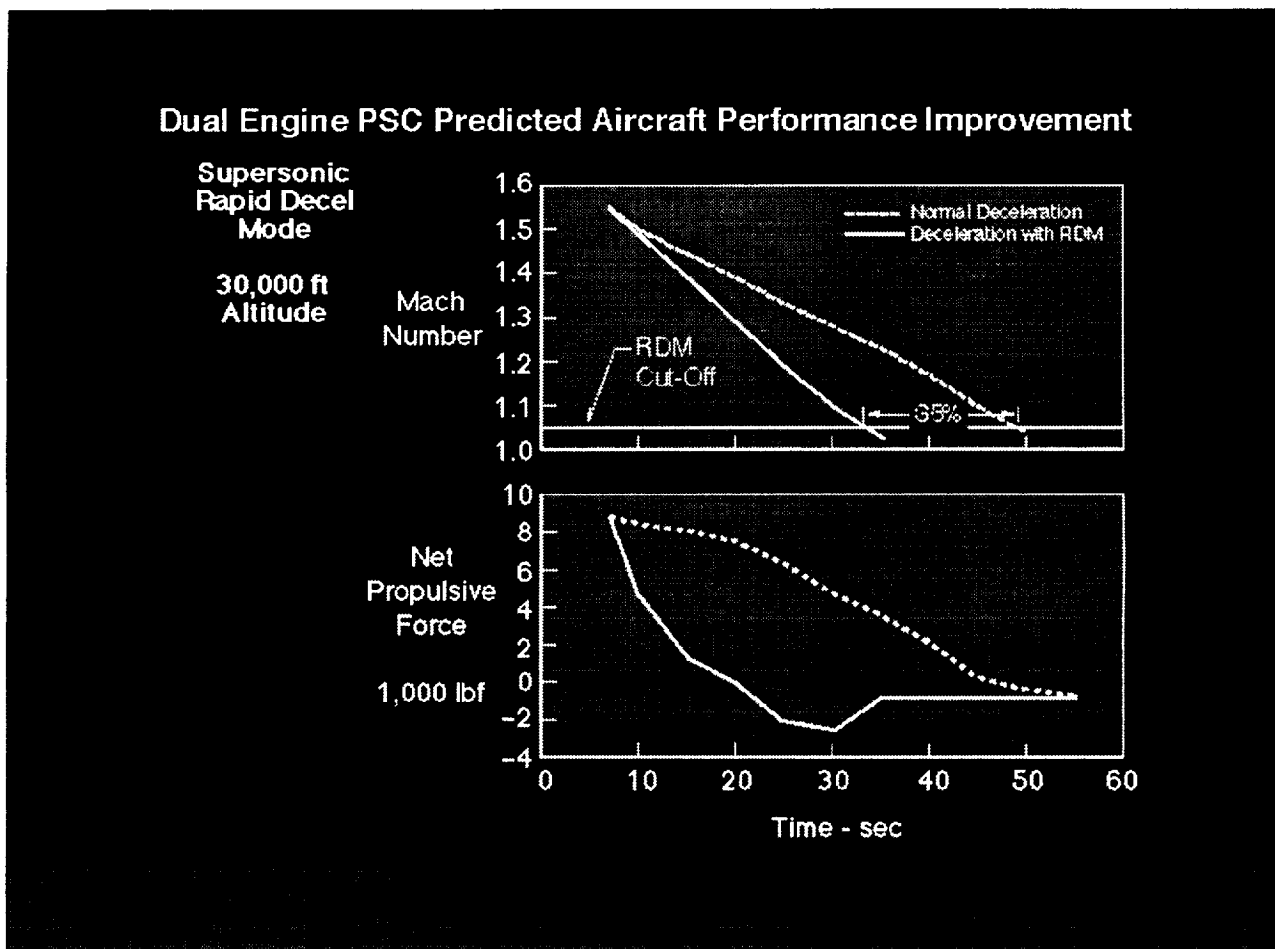
Prediction of a Rapid Deceleration Mode Deceleration

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#)

Paper [\[Index / Prev / Next\]](#) [\[Submit Response / Read Responses\]](#)

[HELP](#) is Available



In the supersonic rapid deceleration mode, thrust is minimized and drag maximized resulting in improved deceleration times.

An idle power deceleration with the Speedbrake retracted was simulated with the Six Degree of Freedom Simulation. An aircraft with PSC Supersonic Rapid Deceleration Mode engaged decelerates from 1.6 to 1.05 Mach

number in 33 seconds where as a baseline aircraft takes 49 seconds. This is a 35% improvement in deceleration time.

Paper [[Index](#) / [Prev](#) / [Next](#)] [[Submit Response](#) / [Read Responses](#)]

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NASA Dryden Flight Research Center

"Rapid Deceleration Mode Evaluation", page 3

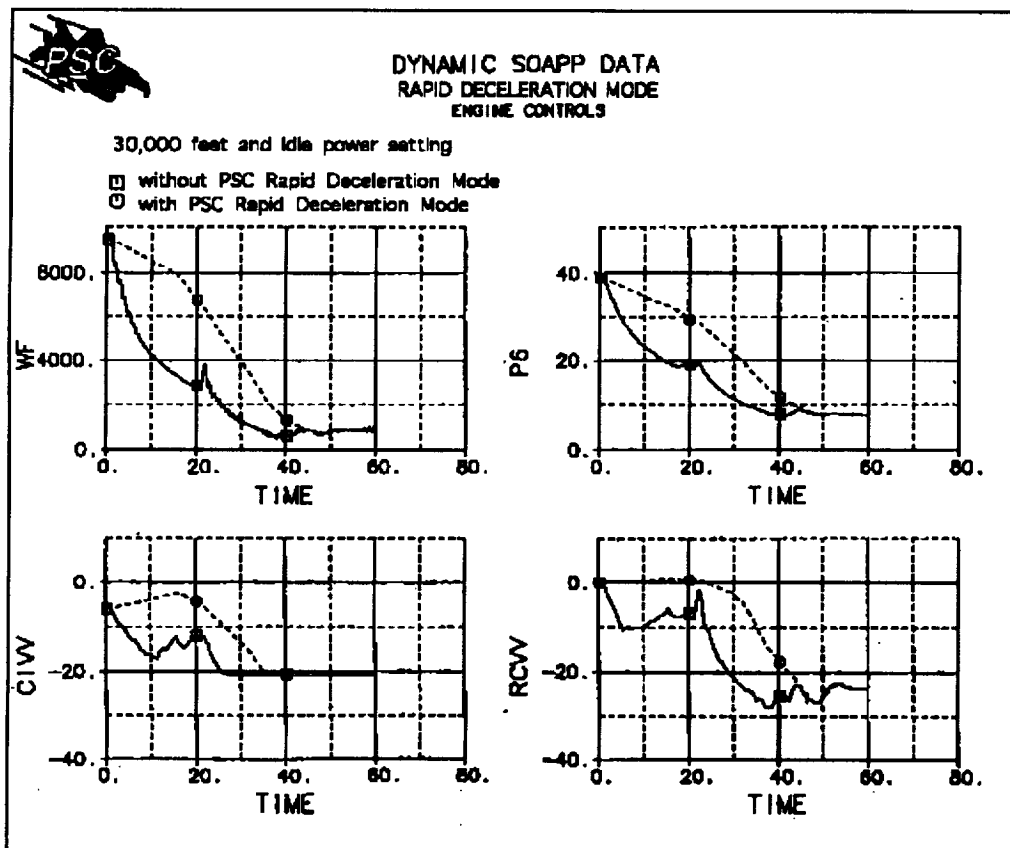
Prediction of Engine Controls for a Rapid Deceleration Mode Deceleration

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#)

Paper [\[Index / Prev / Next\]](#) [\[Submit Response / Read Responses\]](#)

[HELP](#) is Available



The Dynamic Propulsion System Simulation shows how Rapid Deceleration Mode (RDM) achieves these benefits for the 30K deceleration. Fuel flow (WF, pph) and turbine pressure (P6, lb/in²) were reduced. The fan and compressor vanes were trimmed in the cambered direction.

Paper [\[Index / Prev / Next\]](#) [\[Submit Response / Read Responses\]](#)

NASA Dryden Flight Research Center

"Rapid Deceleration Mode Evaluation", page 4

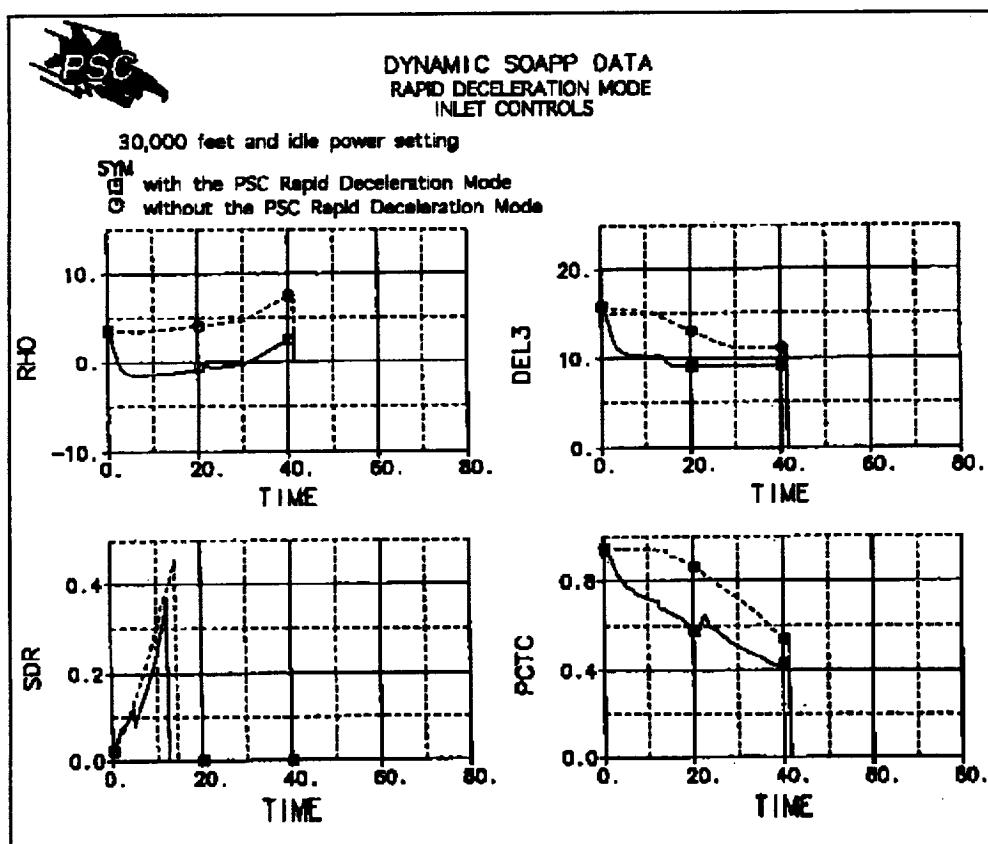
Prediction of Inlet Controls for a Rapid Deceleration Mode Deceleration

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#)

Paper [\[Index / Prev / Next\]](#) [\[Submit Response / Read Responses\]](#)

[HELP](#) is Available

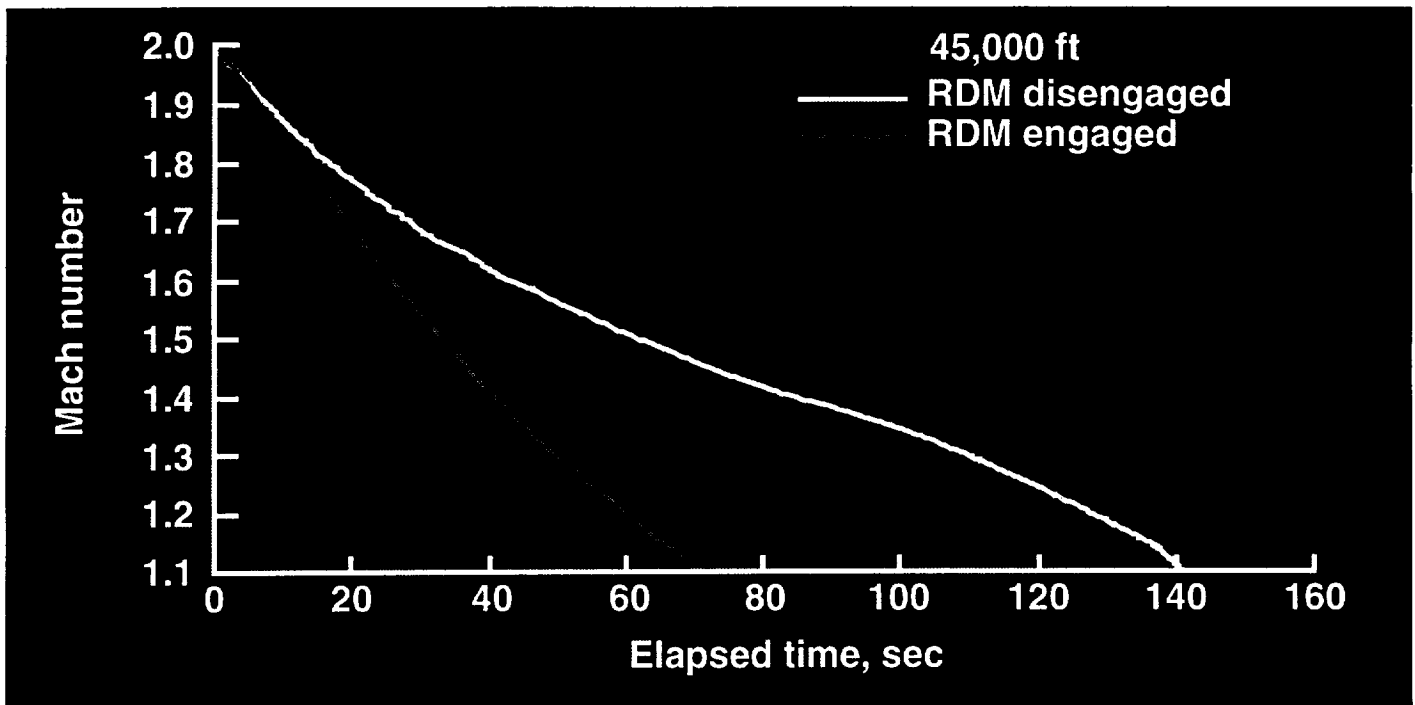


The inlet ramps were positioned to increase inlet and stabilator trim drag. The inlet cowl (rho, degrees) is rotated upward and the third ramp (DEL3, degrees) is moved out of the airflow.

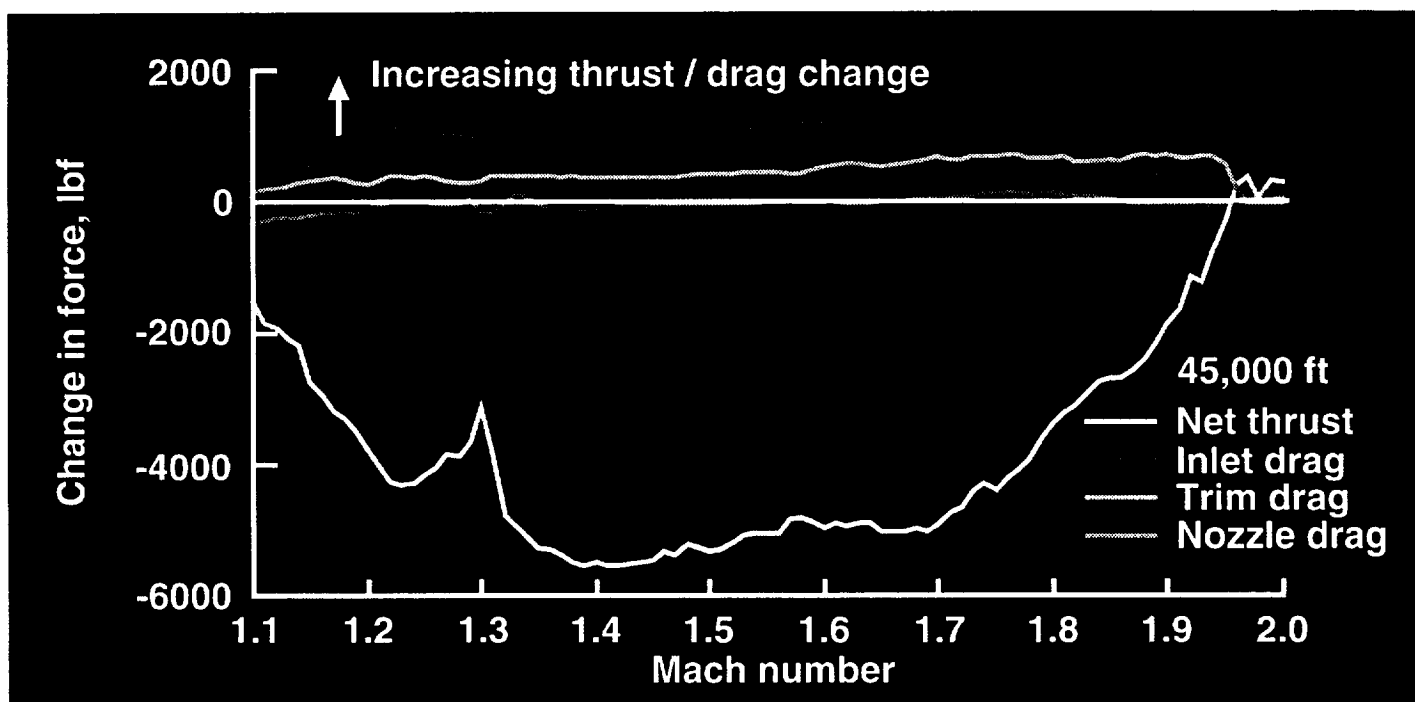
Paper [\[Index / Prev / Next\]](#) [\[Submit Response / Read Responses\]](#)

Author: Timothy R. Conners

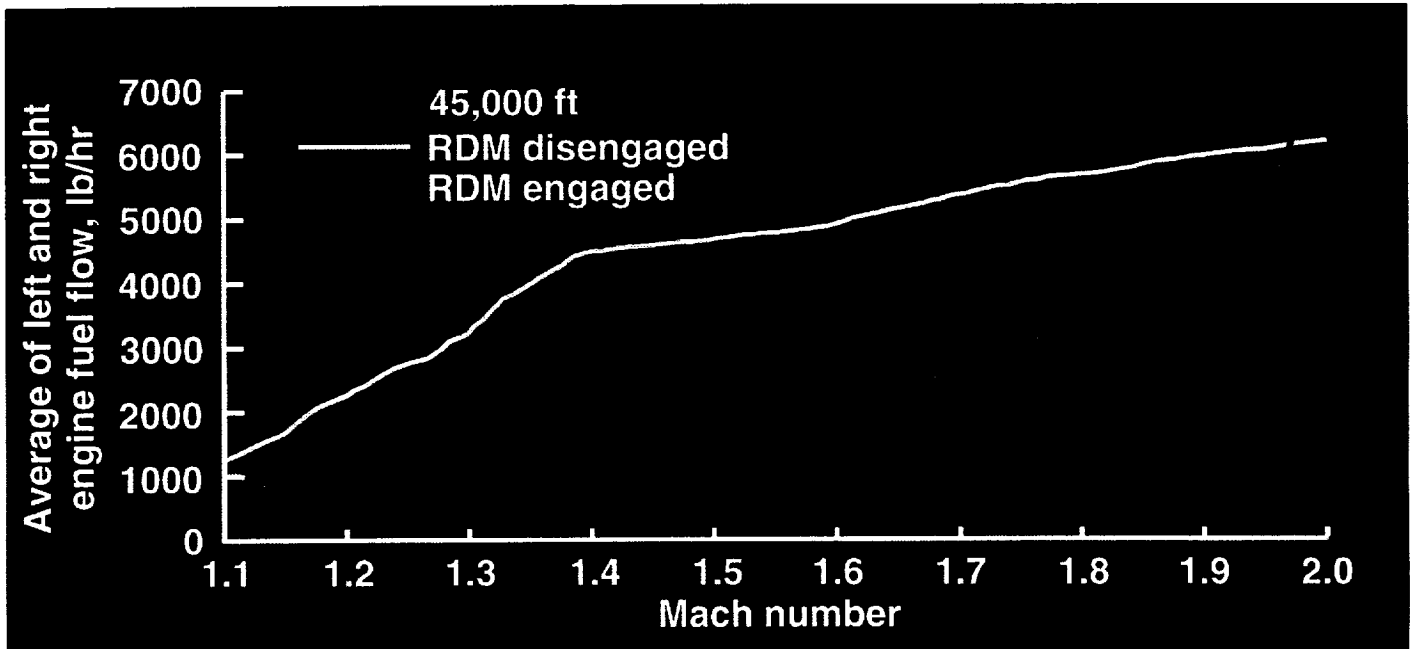
Results from the use of PSC RDM during a supersonic deceleration at 45,000 ft are presented in the figure below. As can be seen, RDM reduced the time to decelerate from Mach 2.0 to 1.1 by 50 percent (from 140 sec to 70 sec).



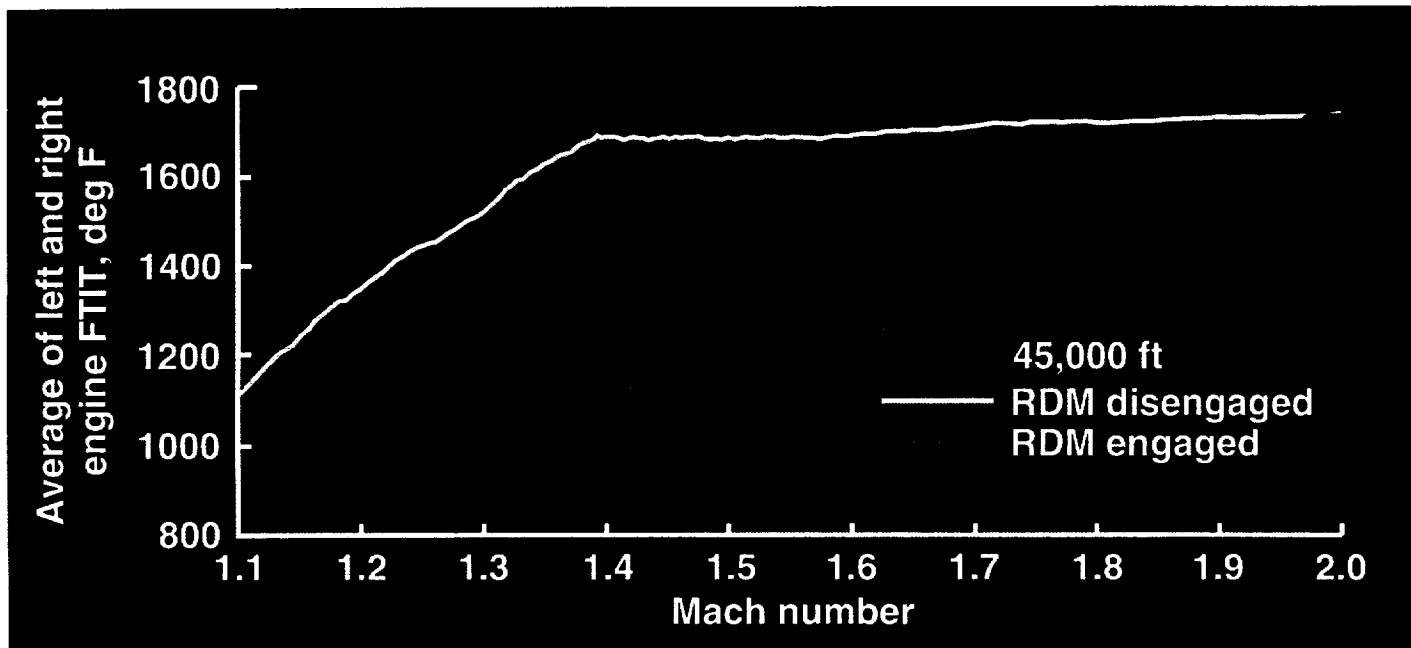
The figure below shows the change in component force and drag resulting from the use of RDM for the above test case. These values were estimated by the PSC on-board model. Net thrust was greatly reduced, primarily as a result of the reduction in engine airflow. Inlet drag was substantially increased by moving the inlet shock system further open, thereby increasing airflow spillage. Trim drag also increased as the inlet cowl was rotated upwards. The change in nozzle drag was minimal.



The figure below compares engine fuel flow as a function of Mach number for the 45,000 ft test condition, and shows the large reduction that occurs with RDM engaged (for example, 62 percent at Mach 1.4).



The following figure shows the correspondingly large decrease in engine operating temperature that occurs simultaneously. For example, FTIT is reduced by 560 deg F (33 percent) at Mach 1.4 with PSC engaged.



No inlet buzz problems occurred using RDM. This mode successfully demonstrated the benefits of integrating the engine control with a thrust calculation algorithm and off-nominal inlet scheduling. Flexibility of PSC in effectively accommodating different performance goals was also proven. In this case, the antithesis of the maximum thrust mode drove the propulsion system to a minimum force value, constrained primarily to an accurate minimum airflow boundary.

Reference: Orme, J. S. and Conners, T. R.; *Supersonic Flight Test Results of a Performance Seeking Control Algorithm on a NASA F-15 Aircraft*; AIAA-94-3210, June 1994.

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"Thrust Stand Test"

Table of Contents

Navigating Around the Workshop:

[\[Workshop Home\]](#) [\[Session Agenda\]](#) [\[Submit Response / Read Responses\]](#)

HELP is Available

CONTENTS:

- [Thrust Stand Test Setup \(p. 1\)](#)
 - [Thrust Stand Test Results \(p. 2\)](#)
-

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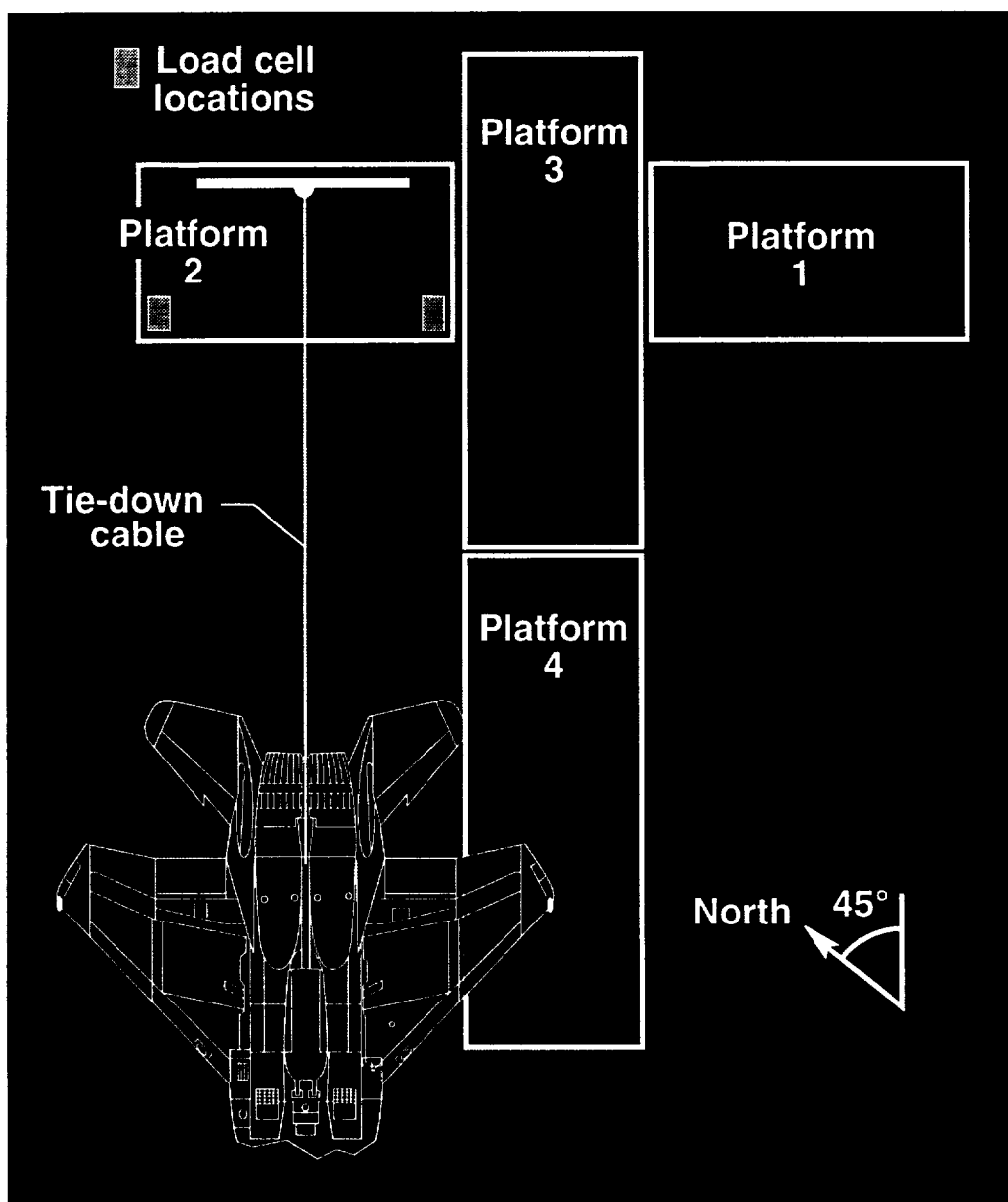
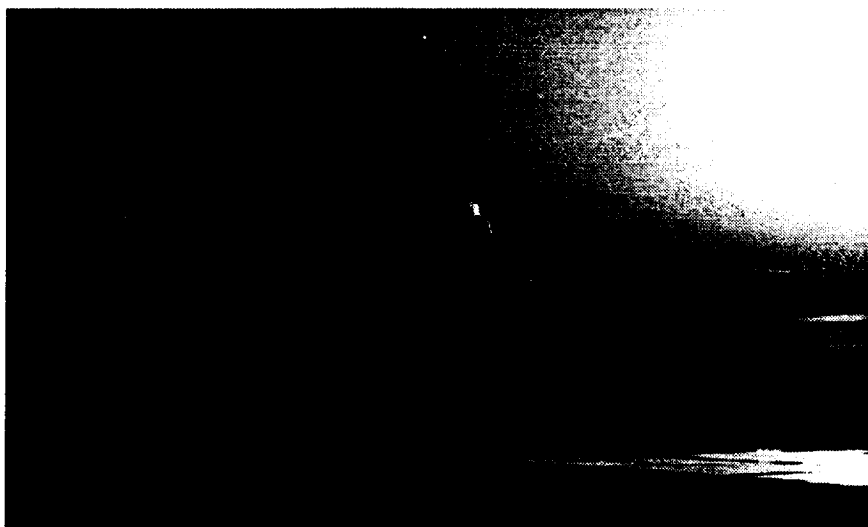
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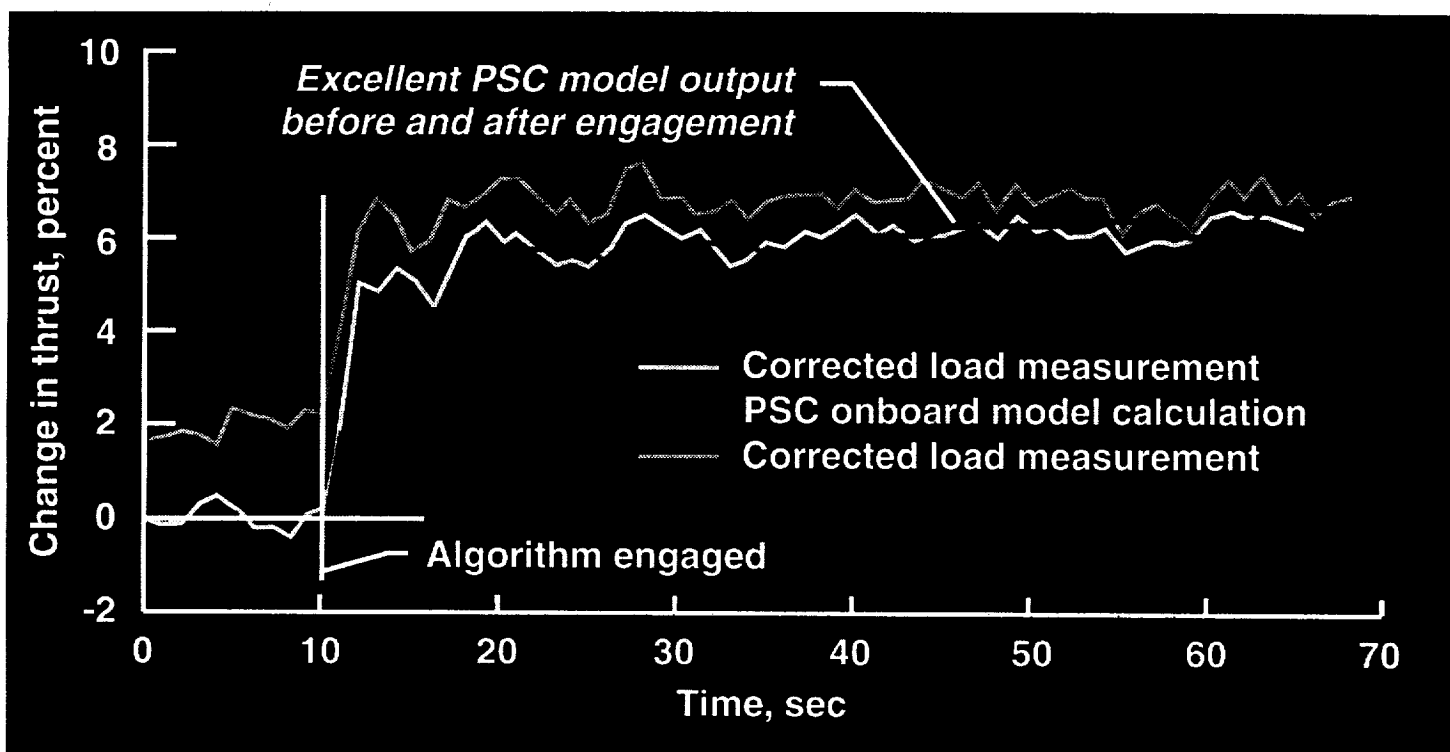
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The PSC algorithm was tested in the F-15 at the Air Force horizontal thrust stand located at Edwards Air Force Base (see figure below for test set-up). There were two primary objectives: 1) to absolutely quantify the performance benefits of PSC using the highly accurate thrust stand measurements, and 2) to directly compare the on-board model thrust estimates to these measurements.



In meeting the first objective, the PSC maximum thrust mode was directly observed to amplify engine thrust by an average of 10 percent at intermediate power and 6 percent at maximum power. PSC also generally performed well at holding constant nominal thrust when using the minimum fuel and minimum fan turbine inlet temperature modes. Bleed air extraction from the test engine was shown to have a substantial impact on the operation of the PSC algorithm.

The load cell measurements were also compared against estimations from several analytical engine performance models, including PSC's on-board estimate and a state-variable model (SVM) based technique. The figure below presents a comparison for a maximum thrust mode test point at maximum augmented power. Two important qualities for each model were assessed: the ability to calculate absolute thrust values, and the capability of measuring the performance across engine transients. In general, the on-board model displayed the best all-around ability at handling off-nominal transient operation and did very well at estimating the absolute net thrust. The SVM generally did not do as well at modeling the true engine performance change during engine transients.



The thrust stand provided the only practical means to compare analytically based thrust calculations with actual measured installed thrust. It proved to be an excellent platform for investigating the dynamic operation of PSC. It directly validated the predicted PSC performance improvements and verified the proper operation of the on-board thrust calculation.

Reference: Conners, T. R.; *Thrust Stand Evaluation of Engine Performance Improvement Algorithms in an F-15 Airplane*; AIAA-92-3747 and NASA TM 104252, July 1992.